Hydrogen Liquefaction Technology using Active Magnetic Regenerative Refrigerator

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Hydrogen has been significantly used as a clean energy carrier for decarbonization and global energy transition. Different hydrogen carriers have been widely utilized, including liquefied hydrogen, ammonia, methanol, liquid organic hydrogen carriers, and compressed gaseous hydrogen. Liquid hydrogen has a much higher volumetric energy density compared to gaseous hydrogen, where it occupies about 1/800th the volume of gaseous hydrogen at atmospheric pressure, making it efficient for storage and transportation. However, liquefied hydrogen has an extremely low liquefaction temperature of 20 K, representing an energy-intensive liquefaction process. Therefore, improving the efficiency of liquefaction significantly reduces its supply costs.

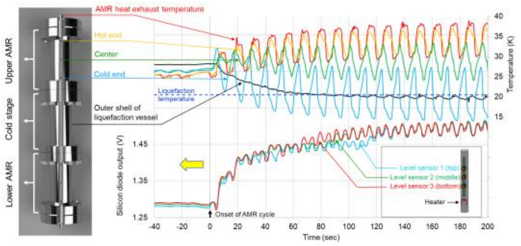

Fig. 1. Hydrogen liquefaction experimental result using AMRR.

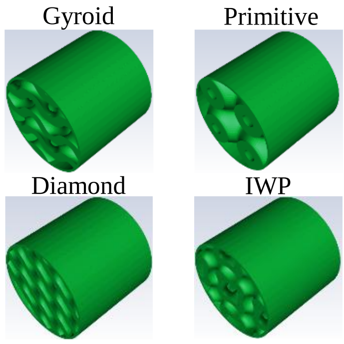

Fig. 2. Proposed TPMS structures for AMRR.

The present study focuses on magnetic refrigeration, which enables an ideal refrigeration cycle without relying on Joule–Thomson expansion, to improve the efficiency of hydrogen liquefaction. Magnetic refrigeration is a cooling technology that utilizes the magnetocaloric effect (MCE) of magnetic materials. When a magnetic field is varied, the magnetic entropy of the material changes, causing a corresponding temperature change. By repeating heat absorption and release between the material and its surroundings, a refrigeration cycle is established. Herein, granular $HoAl_2$ particles have been proposed given their significant specific heat and large MCE, and a heat transfer gas (helium) flows between the particles to induce a temperature gradient within the material. The present system is known as the Active Magnetic Regenerative Refrigerator (AMRR), originally proposed by Barclay[1]. In the late 20th century, studies on AMR systems for hydrogen liquefaction commenced by Janda and Zhang[2]. Currently, successful and ongoing development of AMRR-based hydrogen liquefaction has been carried out at the National Institute for Materials Science (NIMS)[3]. The results demonstrate an achievable hydrogen liquefaction process using an AMRR-based hydrogen liquefaction system (cf. Fig. 1). Meanwhile, for improving heat transfer effectiveness between the HTF and MCM, 3D printing of triply periodic minimal structures or TPMS (e.g., Gyroid, Primitive, Diamond, and IWP, as seen in Fig. 2) are proposed and compared with conventional packed bed AMRR. The TPMS structures are widely known for their superior specific surface area and tunable topology[4]. This could significantly upgrade hydrogen liquefaction efficiency and push boundaries toward reduced hydrogen supply costs.

References

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